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Investment decision for coastal urban development projects considering the impact of climate change: Case study of the Great Garuda Project in Indonesia

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ABSTRACT

As the impact of climate change increases, coastal cities are negatively affected by sea level rise, extreme rainfall, and storm surges. To cope with such climate change impacts, it is essential to invest in climate change adaptation procedures in coastal cities. This paper proposes a rainbow option-based methodology to accurately valuate investments in coastal city development considering climate change. This model is a tool for evaluating the economic feasibility considering the uncertainties of the impacts of climate and urban development projects. The National Capital Integrated Coastal Development (NCICD) project by Indonesian government was used as a case study to validate the effectiveness and applicability of the proposed methodology. The option value of the NCICD project using the proposed model was estimated at US$ 7021 million. The rainbow option, dealing with both climate and market uncertainties, enables decision makers to reasonably assess the value of coastal development projects for their successful execution.

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1. Introduction

Risks related to climate change are expected to increase in urban areas due to heavy rainfall, inland and coastal flooding, landslides, sea level rise, and storm surges (IPCC, 2014). In particular, coastal urban areas are at risk due to accelerated sea level rise and varying rainfall frequencies (Nicholls, 1995). Increasing population, assets, and subsidence further intensify the damage in coastal urban areas (Hallegatte et al., 2013). However, in most coastal urban areas, disaster prevention facilities are not adequately adjusted to accommodate the changing climate and the annual damage in these areas could globally reach a level of US$ 1 trillion (Tran Viet Duc, 2013). If the capacity of the facility is increased through appropriate adaption investment, it is expected that the probability of flood damage will be significantly reduced (Hallegatte et al., 2013). Therefore, coastal cities need to make appropriate adaptation investments reflecting the increasing impact of climate change.

To adapt to climate change, coastal urban areas are introducing various adaptation facilities. The city of Saint Petersburg, Russia, completed the 25 km long Petersburg Flood Prevention Facility Complex, including 11 dams, to prevent coastal flooding in 2011 (Klevannyi and Kolesov, 2015). The U.S. Army Corps of Engineers installed a surge barrier in the New Orleans coastal area in 2013 to prevent damage from hurricanes (USACE, 2013). The Netherlands also invested heavily in disaster prevention facilities to accommodate sea level rise and flood damage due to low and flat terrain. Two notable examples are the Zuiderzee Works and Delta Programme. Zuiderzee Works has been executed since 1918 to build dams, dikes, and drainage facilities. The main objective of this plan is to secure safety against frequent flood damages on the 300 km Zuiderzee coast, improve the water quality, create fresh water, and secure farmland (Van Lier and Steiner, 1982). The Delta Programme is another massive effort to prevent flood damage and provide fresh water. It consists of nine subprograms including embankment reinforcement, coastal area maintenance, and new town development (Delta Commissioner, 2010).

Climate change adaptation in urban coastal region requires large-scale and long-term investments. Some researchers have carried out studies on the economic evaluation of coastal urban projects to adapt to climate change. Storch and Downes (2011) assessed the flood risk of urban development projects in Ho Chi Minh City, Vietnam, based on sea level rise scenarios. They used a

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geographic information system (GIS) to quantitatively evaluate the impact of sea level rise on the projects. De Bruin et al. (2014) assessed the economic feasibility of various adaptation alternatives for low-lying coastal areas, taking into account the impacts of climate change. They proposed a probabilistic approach reflecting the uncertainty of climate change in the Zuidplaspolder region of the Netherlands. Although these aforementioned studies advanced the knowledge of climate change adaptation, there is much room for improvement. One important deficiency is that they did not consider management flexibility such as expansion, reduction, abandonment, and postponement of investments in projects.

Real Options Analysis (ROA) is a method applying the financial option theory, proposed by Black and Scholes (1973), to real assets. This methodology helps people to adopt managerial flexibility to decision-making about projects with high risk and uncertainty (Mun, 2002; Wesseh and Lin, 2016; Kim et al., 2017). Traditional discounted cash flow method uses a deterministic model, while ROA makes decisions that minimize losses and maximize profits (Kodukula and Papudesu, 2006; Kim et al., 2017b).

Some researchers used ROA to assess the value of real estate development projects in urban areas. Amin and Capozza (1993) conducted a real-option-based economic analysis of policies to convert undeveloped land into urban areas, taking into account the characteristics of urban cash flow and various future redevelopment probabilities. Capozza and Sick (1994) developed a land price evaluation model based on the risk preference in urban areas using ROA. Cunningham (2006) analyzed the impact of housing price uncertainty on the development time and vacant land prices in the Seattle area using ROA. Hui et al. (2011) suggested a real option-based methodology that determines the appropriate time to invest in the consideration of the risks of the Hong Kong urban regeneration project. Chen and Lai (2013) proposed a method to determine the optimal building demolition time and city expansion time considering the uncertainty of construction costs and asset sales prices using ROA.

Some researchers applied ROA to the economic analysis of rainfall damage including floods. Woodward et al. (2011, 2014) presented a real option-based decision-making methodology for an appropriate flood disaster prevention system in the Thames Estuary, UK. Park et al. (2014) proposed a real option-based method to determine the expansion time and scale of the drainage infrastructure, considering the uncertainty of flood damage. Anvarifar et al. (2016) presented a real option-based framework for the evaluation of the value of the flexibility of expansion of a multifunctional flood defense system. Chan et al. (2016) assessed the value of an incremental expansion option for the selection of storm protection investments. Buurman and Babovic (2016) presented a real option-based approach suggesting appropriate policies of climate adaptation for flood and drainage in Singapore. Kim et al. (2017a) presented a real option-based economic evaluation framework for urban disaster prevention facilities using climate scenarios.

In the above-mentioned literature, previous studies performed ROA using one representative volatility. Despite the various circumstances faced by individual projects, there are limitations in that they do not allow for multiple uncertainties. In addition, due to the increasing impact of natural disasters, policy makers must develop an urban development plan that reflects the climate characteristics of coastal areas. However, existing studies have not provided an economic assessment tool that can concurrently consider the impacts of climate change and urban development.

This paper differs from previous studies applying the ROA method to urban development projects in two aspects. First, we conducted an economic assessment of a complex project that simultaneously considers climate change adaptation and urban development characteristics. There is no literature available that provides the links between climate change adaptation and economic evaluation of urban development projects. As the damage from climate change becomes worse over time, the impact of climate change on the economic evaluation of urban development is becoming more important. Second, we evaluated the value of urban development projects using the quadrinomial lattice model, which considers multiple uncertainties. The real estate market risk and local risk of natural disasters in cities were simultaneously considered. Therefore, the combined effect of climate change and urban development is adequately reflected in the results of the economic analysis. This study is expected to help decision makers to prepare investment strategies for coastal development projects considering climate change impacts.

2. Methods

It is necessary to introduce disaster prevention facilities in coastal urban development projects to reduce damage caused by natural disasters such as floods, hurricanes, storm surges, and heavy rain. In addition, the construction of residential areas, commercial facilities, and transportation infrastructure facilities is also required. Reducing the potential impact of climate change, such as floods and heavy rain, through disaster prevention facilities increases the benefits of urban development projects. Revenue from property development and transportation fees also benefits the entire project. The value of the project will therefore be determined by the impact of both climate change and urban development projects. We propose a comprehensive method for the valuation of infrastructure investments by considering two uncertainty factors, that is, climate change and the urban development project, using the rainbow option.

2.1. ROA of climate change adaptation

Here, climate change adaptation refers to the use of opportunities to reduce climate-related damage or to increase climate-related profit by adjusting infrastructure systems. The value of such an investment into climate change adaptation can then be expressed as monetary amount equivalent to the potential reduction of future climate damage. However, extreme climatic patterns in coastal areas, such as heavy rain, storm surges, and floods, do not occur every year and greatly fluctuate. With respect to the uncertainty of extreme climate, the ROA method is more effective for the valuation of an investment into climate change adaptation than the traditional discounted cash flow method. In ROA, the underlying asset is calculated from the cash flow expected to occur during the project period. Therefore, the potential reduction of the damage amount, which is made possible by the disaster prevention facility, is transferred to the underlying asset. The investment timing and amount of the facility correspond to the maturity date and strike price of the option, respectively. To consider the uncertainty of the amount of damage from natural disasters, the volatility of potential damage reduction is estimated based on historical climate data. Through this process, the value of the climate change adaptation facility is evaluated.

2.2. ROA of the urban development project

Urban development planning takes into account a wide variety of factors including transportation, water and sanitation facilities, residential patterns, financial issues, social infrastructure expansion scenarios, and timing and order of investments (Hopkins, 2001). Because urban development projects have many uncertainties, more accurate economic assessment is possible with

ROAs than with the discounted cash flow method. The underlying asset of the investment is estimated from the present value of future cash flow revenue such as real estate sales, transportation infrastructure fees, and facility usage charges in urban development projects. The timing of investments in urban development corresponds to the expiration date of the option and the investment amount of the urban development project is calculated as the strike price. Uncertainty factors that represent the risks of urban development projects are replaced by volatility factors. Through this process, ROA of urban development projects can be performed.

2.3. Rainbow option model

The binomial lattice model, which is widely used in ROA, uses a single volatility value taking into account one representative uncertainty factor. However, for projects in which the value changes due to multiple uncertainties, decision makers using the binomial lattice model miss the opportunity to correctly assess the value of the project. The rainbow option model is a ROA method that evaluates the value of a project by reflecting two or more uncertainty factors (Kodukula and Papudesu, 2006). Despite the complexity of the computation, a valuation method that takes multiple uncertainties into account is more accurate than an approach considering only one uncertainty factor (Borison, 2005; Wang and Du, 2016). For the rainbow option model to be valid, multiple uncertainty factors must be independent from each other. If the value of a project is either raised or lowered by two factors, the value of the underlying asset moves from one node to the next based on the quadrinomial lattice model.

To evaluate the value of the rainbow option, the values of the underlying asset (S_0), exercise price (X), option period (T), volatility 1 (σ_1), volatility 2 (σ_2), risk-free interest rate (r_f), and time step (Δt) are required. The underlying asset fluctuates over the four cases, where volatility 1 and volatility 2 rise and fall, respectively, during the option period. Therefore, 4^{t-1} nodes are generated for the t-th year. The time step of the volatilities should be set identically, using the following formula: $\sigma(T_1) = \sigma(T_2) \times \sqrt{T_1/T_2}$, where $\sigma(T_1)$ and $\sigma(T_2)$ are the volatility factors of the time steps T_1 and T_2 (Kodukula and Papudesu, 2006). To calculate the changes in the underlying asset over time, up factor 1 ($u_1 = e^{\sigma_1\sqrt{\Delta t}}$), up factor 2 ($u_2 = e^{\sigma_2\sqrt{\Delta t}}$), down factor 1 ($d_1 = \frac{1}{u_1}$), down factor 2 ($d_2 = \frac{1}{u_2}$), risk-neutral probability 1 ($p_1 = \frac{e^{r_f\Delta t} - d_1}{u_1 - d_1}$), risk-neutral probability 2 ($p_2 = \frac{e^{r_f\Delta t} - d_2}{u_2 - d_2}$), and option value ($C$) are used as variables. If the underlying asset is $S_{0,\,t-1}$ at any time $t-1$ ($1 < t \le T$), the underlying assets at time t are $S_{0,\,t-1}u_1u_2$, $S_{0,\,t-1}u_1d_2$, $S_{0,\,t-1}d_1u_2$, $S_{0,\,t-1}d_1d_2$, respectively (Fig. 1). The option is exercised if the underlying asset value of the option expiration year (T) is greater than the exercise price (X). If the value of the underlying asset in year T is smaller than the exercise price (X), the value of the option becomes 0 and the option is abandoned. If the option value of any $t+1$ ($1 \le t < T$) year node is $C_{u_1u_2}$, $C_{u_1d_2}$, $C_{d_1u_2}$, or $C_{d_1d_2}$ the value of the option C_t is calculated as shown in Eq. (1).

$$C_t = e^{-r_f\Delta t}\left[p_1p_2C_{u_1u_2} + p_1(1-p_2)C_{u_1d_2} + (1-p_1)p_2C_{d_1u_2} + (1-p_1)(1-p_2)C_{d_1d_2}\right] \quad (1)$$

Disaster prevention facilities for the adaptation to climate change are introduced by governments, or local governments, to protect the safety of coastal areas. Government decision makers should take not only the profits generated from urban development projects into account but also the economic benefits of climate adaptation when judging the feasibility of the project. This is because the climate-related damage in coastal cities is increasing and reducing the damage is a long-term benefit improving the city's financial structure. In this context, the underlying asset can be evaluated with the same option model considering the two features simultaneously. Because the value of the option changes due to the two uncertainties, the value moves up or down in four directions as the unit time changes. The option model that changes in four directions can be calculated with the rainbow option valuation method (Fig. 2). The two uncertainty factors of the rainbow option are assumed to be independent from each other.

3. Case study

3.1. Project description

Jakarta, the capital of Indonesia, is located in the coastal area northwest of Java Island and has a population of more than 9.6 million as of 2010 (Statistics Indonesia, 2012). The city covers an area of 662 km^2 and is one of the most densely populated cities in

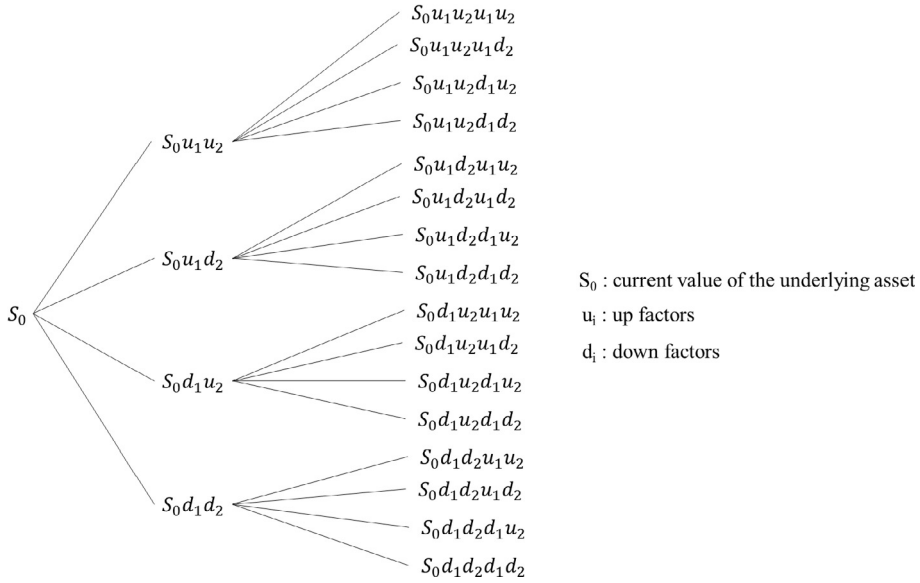

Fig. 1. Quadrinomial tree for the rainbow option model.

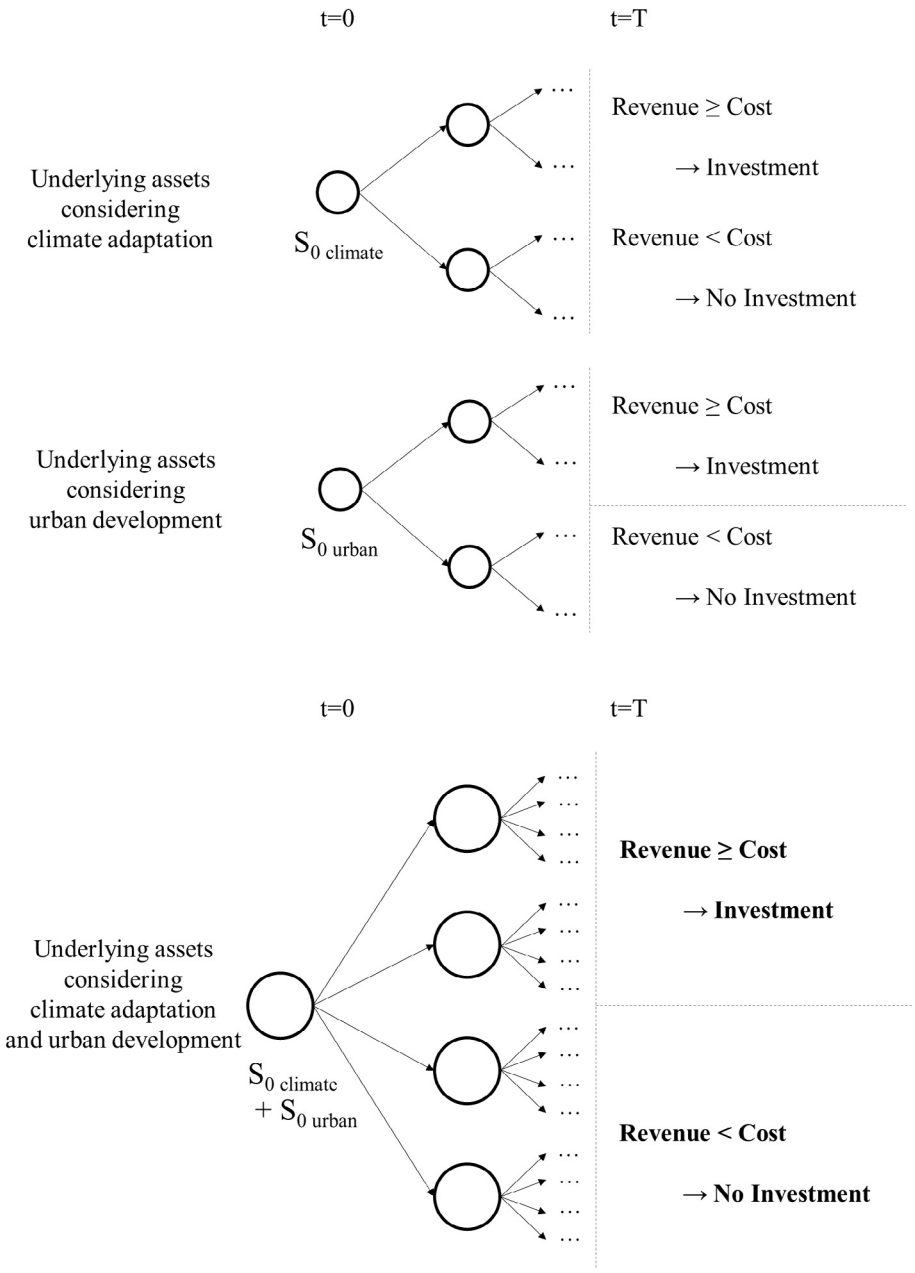

Fig. 2. Combination of climate adaptation and urban development option models.

the world (Firman et al., 2011). Because 40% of the Jakarta area is below sea level, severe flood damage occurs due to heavy rainfall (Firman et al., 2011). Recently, Jakarta suffered rapid flood damage due to sea level rise and heavy rain. In February 2007, the Jakarta area suffered massive flood damage of US$ 967 million, resulting in 80 deaths and 500,000 refugees (Brakenridge, 2012); 75% of the Jakarta area was flooded and some areas were flooded up to 4 m (Brakenridge, 2012). In January 2013, 29 people were killed and more than 37,000 people were displaced due to heavy floods (The World Bank, 2014). Such flood damage is expected to intensify in the future due to the impact of climate change (Budiyono et al., 2015).

The government is conducting the NCICD project investing up to US$ 37.6 billion to reduce flood damage. The NCICD project was designed to construct a 32 km seawall, pump facility, and coastal reservoir (Fig. 3). In addition, the project will generate major profits through the land fill by selling real estate such as the Central Business District (CBD) and hotels and residential buildings (1250 ha). Real estates are built in about 486 ha area, 57% area is used for housing, 31% is for office, 7% is for retail, and the rest is for industrial use. In detail, it is expected that US$ 7200 million in the housing sector, US$ 11,400 million in the office sector, US$ 3900 million in the retail sector and US$ 100 million in the industry sector are estimated to be generated (Coordinating Ministry for Economic Affairs, 2014). The real estate development business accounts for 84% of the project's total revenue and plays an enormously important role in project success. The construction of transportation infrastructure, such as roads and railways, is also included. Through this project, flood damage caused by sea level rise, extreme rainfall, and subsidence can be reduced. The urban development in the coastal area has the potential to lead to economic development and solve residential issues and drinking water problems.

The project includes three construction phases. Phase A is a

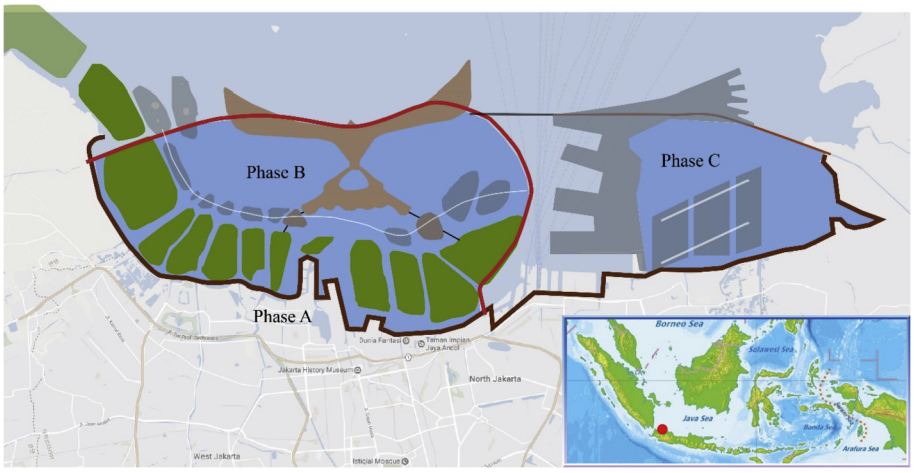

Fig. 3. National Capital Integrated Coastal Development (NCICD)-integrated development plan (Bramm and Leushuis, 2014; NGII, 2017).

project to reinforce existing dikes to ensure safety from flood damage. Phase B includes a project to build a large-scale sea embankment and land fill on the northwestern coast of Jakarta, the shape of which resembles Garuda, a legendary bird used as symbol of the Indonesian nation. This Garuda land fill will produce a waterfront city with 300,000 inhabitants and 600,000 workers. In addition, the project includes facilities, such as roads and high-speed railways, to expand infrastructure facilities. Finally, Phase C is a project to build a seawall in northeastern Jakarta and to create a new economic development zone. Phase C is not considered in this study because a concrete plan has not been established yet.

According to the NCICD economic assessment report, Phase A, a project for flood safety, such as existing embankment reinforcement, will require an investment of US$ 2077 million (Bramm, 2014). Phase B requires an investment of US$ 18,598 million and includes construction of external sea dikes, land fill, real estate development, and transportation facilities (Bramm, 2014). It is expected that a benefit of US$ 26,861 million will be generated from land reclamation projects and transportation infrastructure fee revenues (Bramm, 2014). Considering the total investment, the Net Present Value (NPV) of the NCICD project is US$ 1634 million (Keuning, 2014). Table A-1 shows detailed information about the investment in present values based on year 2015.

3.2. Estimation of benefits from potential flood damage mitigation

According to a report by the Ministry of Public Works (2011), the expected rate of economic growth reduction due to the flood disaster in the Jakarta region was estimated to be 0.55% in 2010. Assuming a 1 m sea level rise scenario, the rate of economic growth reduction is expected to increase to 0.74% by 2050 if climate change adaptation facilities are not introduced. If adaptation facilities are introduced, this ratio will only increase by 0.65% by 2050. The adoption of flood adaptive facilities is expected to provide a 0.06% increase of the average Jakarta economic growth rate between 2030 and 2050. Therefore, we calculated the annual benefit of flood damage reduction resulting from the NCICD project as 0.06% of the Jakarta Gross Regional Domestic Product (GRDP). The project period was assumed to be 35 years, considering the lifespan of general infrastructure facilities. In 2016, the value of GRDP in Jakarta was 1,539,376,654 million rupiahs (in 2010 value), which was converted into dollars using the Bank of Korea's exchange rate statistics (Statistics Indonesia, 2017; Economic Statistics System, 2017). The GRDP was assumed to grow by 6.08%, that is, the average growth rate of the Jakarta GRDP. Based on this assumption, the potential flood damage reduction benefit of the NCICD project was estimated to be US$ 4326 million in 2015.

3.3. Estimation of volatility

The value of coastal urban development projects depends on the degree of flood damage. The capacity of flood disaster prevention facilities is fixed, while flood damage due to heavy rains or storm surges changes. If future climate change intensifies and the introduction of disaster prevention facilities significantly reduces potential flood damage, the value of the project will increase and the investment will be successful. On the other hand, when flood damage from climate effect is scarce, the project introduction has no potential benefit and investment can lead to large losses. Therefore, the volatility of the project can be calculated based on the uncertainty of flood damage.

The value of the project also varies depending on the success of the urban development project. The Jakarta NCICD project includes land reclamation, roads, MRT (Mass Rapid Transportation system), and other facilities. As shown in Table A-1, more than 80% of the project revenue is determined by sales of real estate including residential, office, retail, and industrial facilities, developed on reclaimed land. Real estate sales are the uncertainty factor that is strongly influenced by economic conditions. If the economy booms, the increase in the demand for real estate can lead to an increase in the sales price, resulting in excess profits, which can greatly increase the profit of the project. If the market is in recession, the real estate market will significantly shrink and the project will suffer huge economic losses. Accordingly, the uncertainty of the real estate business is an important factor affecting the value of the project. In this section, we describe the process of estimating the uncertainty of the flood damage and uncertainty of the real estate market as volatility.

3.3.1. Estimating the uncertainty of the climate change impact

To predict the volatility of the flood mitigation profit, the volatility of the flood damages of the past 40 years in Indonesia has been estimated as an uncertainty factor. Fig. 4 shows Indonesia's past flood damage based on the disaster database of the Center for Research on the Epidemiology of Disaster (CRED) established by the World Health Organization (WHO) and Belgian government (CRED, 2017). We used the Indonesia average Consumer Price Index (CPI) interest rate of 10.15% from 1976 to 2017 to convert the data to present values in 2017. Because flood damage does not occur every year, the volatility of the 10-year damage amount was calculated

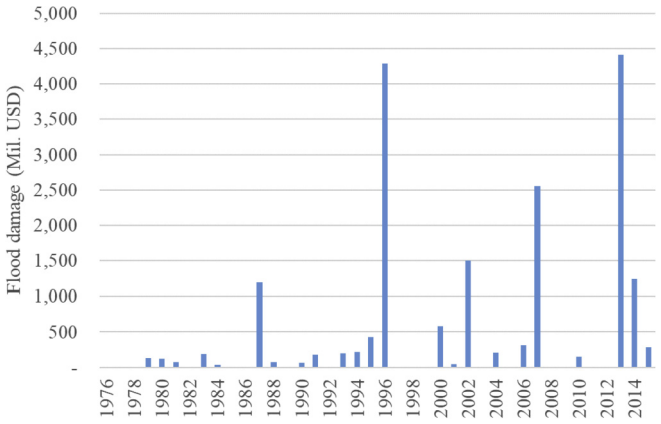

Fig. 4. Trends of historical Indonesia flood damage.

using the logarithmic cash flow returns method and converted into an annual unit. The variability due to climate impact was estimated to be 58.86% on the 10-year basis. When converted to the annual basis, the volatility of flood damage in Indonesia was estimated to be 18.61%.

3.3.2. Estimating the uncertainty of the urban development impact

To estimate the uncertainty of urban development projects, we used quarterly GDP data of Indonesian real estate from 2000 to 2014 (Fig. 5). Indonesian real estate GDP data are based on financial statistics of the Bank of Indonesia (Bank Indonesia, 2017). Based on the logarithmic cash flow returns method, the quarterly volatility was estimated to be 2.37%, which translates into an annual volatility of 4.74%.

4. Results and discussion

As previously mentioned, the rainbow option model was used to calculate the value of the project. Phases A and B require initial investments of US$ 2077 million and US$ 18,598 million, respectively. Considering the average CPI inflation rate of 5.71% from 2007 to 2016, the investment amount of Phase B is US$ 20,783 million after two years. The present value of future revenues based on real estate sales and transportation fees is US$ 26,861 million and the economic benefit from climate change adaptation facilities is expected to be US$ 4326 million. The value of the underlying asset, excluding operation and maintenance (O & M) costs of US$ 4552 million, is US$ 26,635 million. The detailed input variables are shown in Table 1.

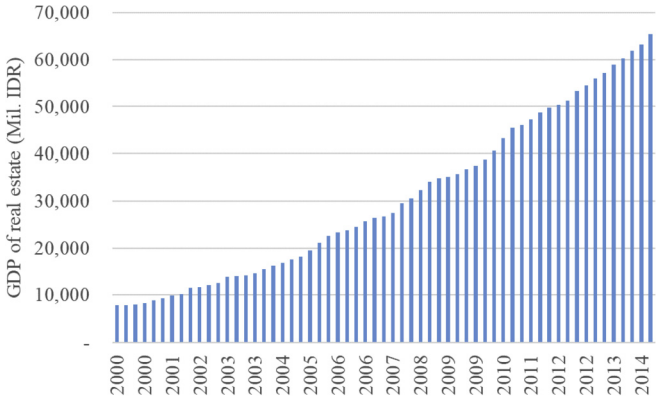

Fig. 5. Trends of the historical Indonesia real estate GDP.

Table 1
Calculation variables for ROA.

Input parameters	Detailed description of input parameters	Value
Underlying asset	Revenue of urban development business + Flood reduction economic benefit − O & M cost	US$ 26,635 million
Strike price 1	Investment cost in Phase A (year 1)	US$ 2077 million
Strike price 2	Investment cost in Phase B (year 3)	US$ 20,783 million
Risk-free interest rate	Average 30-year US treasury rate	3.48%
Volatility 1	Historical flood damage in Indonesia (1976–2015)	18.61%
Volatility 2	Real estate GDP in Indonesia (2000–2014)	4.74%

Fig. 6 shows the project value results using the rainbow option method. In year 3 in which Phase B investments are made, the underlying asset includes $4^{(3-1)} = 16$ cases, taking into account flood damage and real estate market uncertainties. If the value of the underlying asset during this year is greater than the investment amount in Phase B (US$ 20,783 million; marked green in Fig. 6), investment in the project will be implemented. On the other hand, if the value of the underlying asset in year 3 is less than the investment amount in Phase B (peach color in Fig. 6) the investment is abandoned. As a result of the rainbow option valuation, the option value of the Phase B investment in year 1 is calculated to be US$ 9098 million. This value is greater than US$ 2077 million, which is the investment amount of Phase A. Therefore, the project will have an option value of US$ 7021 million (US$ 9098 million − US$ 2077 million), which is US$ 1061 million higher than the value of the

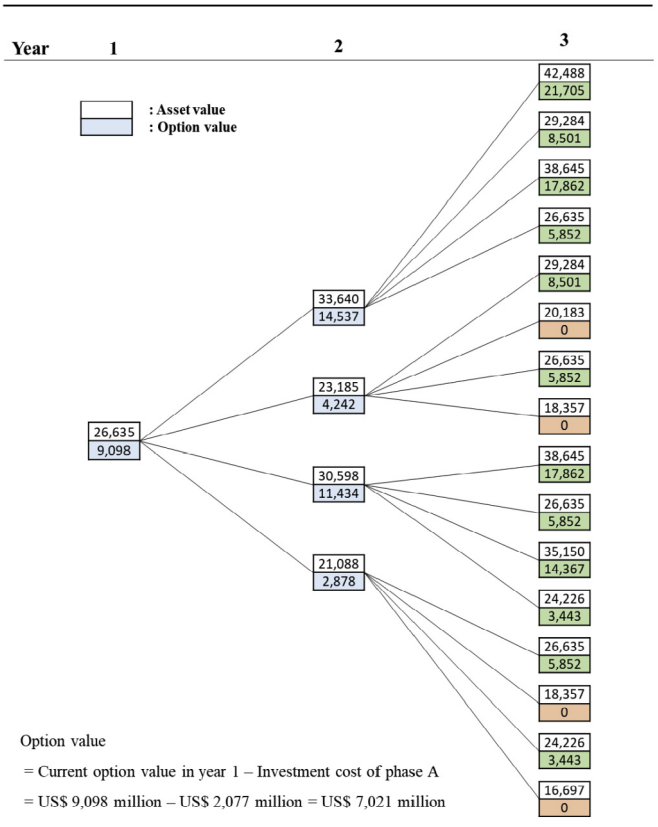

Fig. 6. Quadrinomial lattice for the rainbow option of the National Capital Integrated Coastal Development (NCICD) project.

Table 2
Results for rainbow option analysis.

	NPV	Underlying asset	Option value	Option premium
Result (US$ million)	5960	9098	7021	1061

traditional NPV (US$ 5960 million) (Table 2). In other words, investors can obtain an option premium of US$ 1061 million as a result of the ROA, considering uncertainties of the impact of climate change and urban development projects.

The value of the project was assessed based on two uncertainties, Indonesia's past flood damage and real estate GDP volatilities. We used fixed volatility values; however, these values may change over time depending on future climate change and real estate market trends (Fig. 7). Since there are various external factors involved in the real estate market, it is difficult to predict whether future real estate volatility will increase or decrease. However, uncertainties in climate patterns such as heavy rains, storm surges, and sea-level rise are evidently rising (IPCC, 2014). As a result, the volatility of climate damage is expected to increase in urban areas. Accordingly, the investment value of urban development projects considering climate change impact is anticipated to grow up in the future.

5. Conclusion

In this study, we proposed a method to estimate the value of coastal urban development projects considering climate change using ROA. We used the rainbow option method to reflect the impact of climate change on the value of urban development projects, which considers multiple uncertainties. We assessed the value of the option to perform or abandon the investment, taking into account the management flexibility embedded in the project. This study made three important contributions. First, to the best of our knowledge, this is the first attempt to provide a linkage between the value of climate change adaptation facilities and coastal urban development. Given the increasing flood damage trends in coastal cities, economic analysis methods linking urban development projects to climate change impact will become more important. Second, we identified two important uncertainty factors of the project and assessed the value of coastal urban development projects using a quadrinomial lattice model. This model assesses the precise value of the options embedded in the project, taking into account various uncertainties that were not considered in the existing single volatility valuation method. Third, we proposed a multipurpose infrastructure valuation method that performs complex functions. If the value of a project fluctuates due to multiple uncertainty factors, more precise valuations can be made using the proposed methodology.

This study has limitations. First, only two uncertainty factors were considered in our study, although the NCICD project selected for the case study is a large-scale national project carried out by the Indonesian government. This project is influenced by various external factors such as economic, political, social, and environmental conditions. Project planning, design, time of investment, and participants can change over time. The value of the project can significantly increase or decrease due to uncertainties that have not been anticipated. Agent-based model methodologies can be used to supplement this problem. This method can analyze the decision making of various agents in the urban area and take into account various uncertainty factors which were not considered in this study. Second, the future technical capability of the contractor was not sufficiently considered. Due to technological advances, the contractor may be able to finish the construction effectively with less cost or time. If such private risk is considered, a more accurate project value evaluation will be possible. Third, we assumed a fixed volatility value based on the uncertainty of past flood damage amounts. However, future climate change trends are expected to be more volatile than historical data. Past flood damage data cannot account for all of the volatility of extreme weather events that may occur in the future. Future studies will be able to more accurately assess the value of coastal urban development projects by predicting volatility through future climate scenarios.

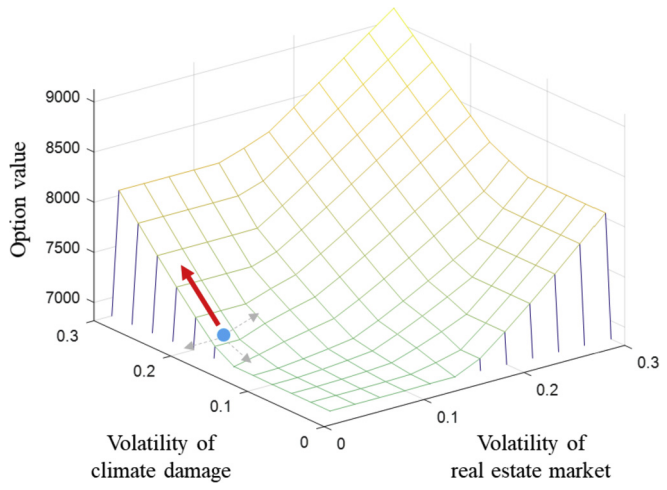

Fig. 7. Future project value trends based on two uncertainties.

Acknowledgments

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Appendix

Table A-1
Detailed information about National Capital Integrated Coastal Development (NCICD) [adapted from Keuning (2014)].

	Investment (US$ million)	O & M (US$ million)	Revenue (US$ million)
Flood Safety (Phase A)			
Coastal defense	−582	−200	
River dikes	−476	−100	
Pumping stations	−294	−100	
Resettlement	−725	−200	
Subtotal	−2077	−600	
Integrated Development (Phase B)			
Outer seawall	−3765	−1100	
Pumping stations	−665	−200	
Locks/Sluices	−198	−200	
Land reclamation (1250 ha)	−8930	−1000	22,600
Toll (national roads)	−3439	−800	1626
MRT	−958	−160	2023
City roads/Toll	−643	−200	612
Lagoon operations		−292	
Subtotal	−18,598	−3952	26,861
Total	−20,675	−4552	26,861

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